THE ESTIMATION OF THE MATERIAL CORROSION BASED ON PREVIOUS DATA AND COMPARE WITH ON-SITE TEST AT GEOTHERMAL FIELD.

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ABSTRACT

The material selection of pipeline and well in geothermal plant is important for risk management to prevent scale and corrosion problem. Especially, in acidic condition with high temperature region, the material corrosion problem becomes more serious.

To solve this problem, we started the project of the Development of Geothermal Power Plant Risk Assessment System supported by NEDO from 2014. In this project, based on the data collected from 1974 to 2002 at AIST, we made calculation system to estimate the corrosion rate from pH, temperature and material component.

And we try to compare the calcurated data with the on-site corrosion test at Kakkonda geothermal field at FY2015. The corrosion rate of carbon steel at Kakkonda is about 1.6mm/year at on-site examination under pH 3.6 and 145 ºC and match to the result of calculation based on previous data-base. On the other hand, TN80Cr13 and TN110Cr13S, the calculated corrosion rate is higher than the on-site corrosion rate.

1. INTRODUCTION

In the development of geothermal power plant system, several risks are included related resource and plant operation. These risks directly related with cost and safety of operation.

The risk to the plant is mainly the scale and corrosion at the surface facilities and borehole. In the case of corrosive condition (low pH etc.), the operator have to exchange surface facilities many times or use expensive materials for the surface facilities and borehole. And in the case of many scaling field, the operator have to use the scale inhibitor. These are including cost and safety problem for operating plant. Then, we need the solution for the problem of scaling and corrosion at surface facilities and borehole to reduce the plant risk of geothermal development.

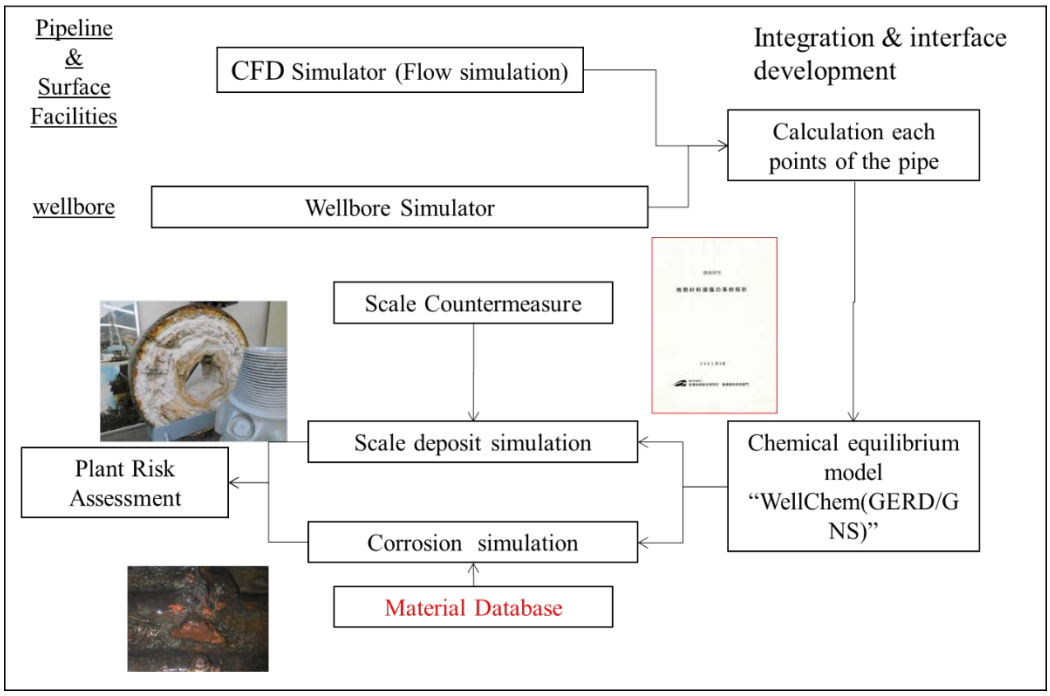

Figure 1: The concept of the project of Plant risk assessment.

Then, New Energy and Industrial Technology Development Organization (NEDO) started the project "Research and Development of Geothermal Power Generation Technology" at FY2013. The project consists of four major purposes and the one of them is "Innovative Technology Development for Promotion of Introduction of Geothermal Power Plant"

We (GERD, AIST and TenarisNKKTubes) proposed the project of "Development of Geothermal Power Plant Risk Assessment System (Prediction, Measure and Management for Scale and Corrosion)". The proposal is accepted at FY2014 for 4 years project. The concept of the project is shown in Figure 1 (Yanagisawa et al., 2016).

The project apply geochemical and flow simulation to estimate erosion and corrosion of material and scaling at surface facilities and borehole. And the result of simulation will be checked using the database of material corrosion and scaling by previous research.

To check the result of simulation, not only the database but also the field test and monitoring is important. Then, the feasibility study of field test is carried out at Kakkonda geothermal power plant in FY 2015.

In this paper, we show the estimation of corrosion rate using previous test data and compare with the field test.

2. ESTIMATION OF CORROSION RATE

The Sunshine project (from 1974 to 2002), AIST-Tohoku (Sendai) branch carried out the survey of erosion and corrosion in geothermal power plant pipelines. The on-site survey was carried out at existing power plant (Onikobe, Matsukawa, Hachobaru) and at developing filed (Yamagawa, Sumikawa). And the several laboratory tests were carried out, for example, the stress corrosion, galvanic corrosion, acidic corrosion using autoclave and flow test. From these test, the relationship between corrosion rate and corrosion environment for different alloy elements has been summarized (Kurata et al., 1995, Sanada et al., 1995, Sanada et al., 1997, Sanada et al., 2000). And the deeper reservoir at high temperature, corrosive hypersaline fluid exist (Kasai et al., 1998, NEDO, 1999)

From the results of test data, the corrosion rate depends on temperature, pH and the chemical composition of material. For index of corrosion rate by material chemical composition, the idea of Cr equivalent was introduced (Kurata et al., 1992). The ratio of the contribution to corrosion resistance of Cr and elements other than Cr was deduced from the experimental data. The method of analysis is outlined briefly as follows.

$$\mathrm{Log\ (C.R)} = A_0 + A_1\{\mathrm{Cr}\}_{eq} \quad (1)$$

where (C.R), $\{Cr\}_{eq}$ are the corrosion rate (mm/y), Cr equivalent (mass %), respectively. And the alloy elements of the material are formulated by first converting to Cr equivalent, defined as follows.

$$\{\mathrm{Cr}\}_{eq} = \mathrm{Cr} + B_0C + B_1Si + B_2Mn + B_3P + B_4S + B_5Ni + B_6Mo + B_7Cu \quad (2)$$

Since Cr is the element which serves as the fundamental component of corrosion resistant materials, the contributions of other elements to corrosion resistance were expressed in terms of Cr.

The pH, temperature and corrosion satisfy the following equation:

$$\mathrm{C.R.} = K \exp\{-En/RT\}\ [H^+]^n \quad (3)$$

where K, En, $[H^+]$, n, R, are constant, activated energy, concentration of hydrogen ion, reaction degree of hydrogen ion, gas constant

Taking logarithms of equation (3), we obtain as follows:

$$\log(\mathrm{C.R.}) = \log K + 0.4343En/(RT) + n\log[H^+] \quad (4)$$

In equation (4), $\log[H^+]$ denotes the pH and logK is a constant based on factors, other than pH or temperature, which affect corrosion rate. Then, the corrosion rate can be related linearly to Cr equivalent and corrosion factors by

$$\log(\mathrm{C.R.}) = C_0 + C_1\{\mathrm{Cr}\}_{eq} + C_2(\mathrm{pH}) + C_3(1/T) \quad (5)$$

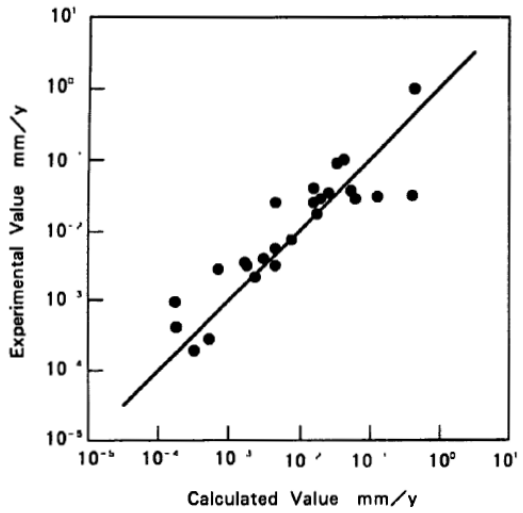

Figure 2: Correlation between calculated value and on-site experimental value at several geothermal field (from Kurata et al., 1995).

Using the results of corrosion tests for various materials and the corresponding corrosion factors, the regression method was used to obtain the coefficients. The experimental data from other fields; comparison between the calculated and experimental data shown in Figure 2 gives reasonable agreement.

And in the equation (2) and (5), B and C are converted in the case of HCl acid condition as follows;

$$Cr_{eq} = \mathrm{Cr} - 13.73\,C + 1.598\,Si - 0.433\,Mn + 27.28\,P - 51.12\,S + 0.237\,Ni + 0.712\,Mo - 1.060\,Cu\ (\mathrm{wt\%})$$

$$\log(\mathrm{C.R}) = 6.696 - 1930(1/T) - 0.622(\mathrm{pH}) - 0.085(Cr_{eq})$$

The list of calculation results of Cr_{eq} is shown in Table 1. The carbon steel shows the negative value and the stainless steel shows about 20. And this value shows that the carbon steel is corrosive material.

Table 1: The list of the Cr equivalent of several materials.

	C	Si	Mn	P	S	Ni	Cr	Mo	Cu	Creq
J55（Carbon Steel）	0.45	0.24	0.96	0.022	0.025				0.01	-6.8779
N80(Carbon Steel）	0.24	0.16	1.1	0.028	0.021				0.01	-3.8149
SM80S(Low Metal Alloy)	0.23	0.17	0.67	0.015	0.004	0.03	1.03	0.24		-1.76364
STBA24-2(Low Metal Alloy)	0.09	0.42	0.5	0.019	0.006	0.05	2.31	0.96	0.02	2.45713
STBA25-2(Low Metal Alloy)	0.09	0.49	0.47	0.024	0.007	0.06	5.09	0.5	0.02	5.12211
STBA26-2(Low Metal Alloy)	0.13	0.71	0.42	0.025	0.006	0.16	9.09	0.96	0.02	9.37574
MS13-2(Low Metal Alloy)	0.21	0.26	0.57	0.028	0.005	0.69	11.55	0.92	0.03	10.19398
SUS304(Stainless）	0.049	0.74	0.94	0.026	0.005	9.25	18.36	0.08	0.07	21.23982
SUS316(Stainless）	0.031	0.68	0.93	0.02	0.004	11.5	16.53	2.2	0.37	21.81354
SUS316L(Stainless）	0.018	0.49	1.01	0.02	0.018	13.95	17.12	2.47	0.06	21.97238
Incolloy 800(High Ni Stainless）	0.043	0.52	0.84	0.004	0.0004	35.86	22.5			30.964342
22-42(High Ni Stainless）	0.02	0.38	0.49	0.013	0.001	41.5	21.6	2.87	1.71	35.71553
HR13-2(Ni base metal）	0.015	0.52	0.76	0.001	0.003	48.37	24.07	6.2	0.96	41.13554
Hastelloy G-3(Ni base metal）	0.008	0.37	0.82	0.014	0	43.978	22.84	6.98	1.84	40.691226
MA625(Ni base metal）	0.019	0.25	0.27	0	0.002	62.779	20.45	8.37	0.09	41.302943
Inconel 718(Ni base metal）	0.039	0.06	0.11	0.003	0.003	52.76	17.8	3.09	0.16	32.11506

Based on above equation, we make the calculation system using Microsoft excel. The sample of this system is shown as Figure 3.

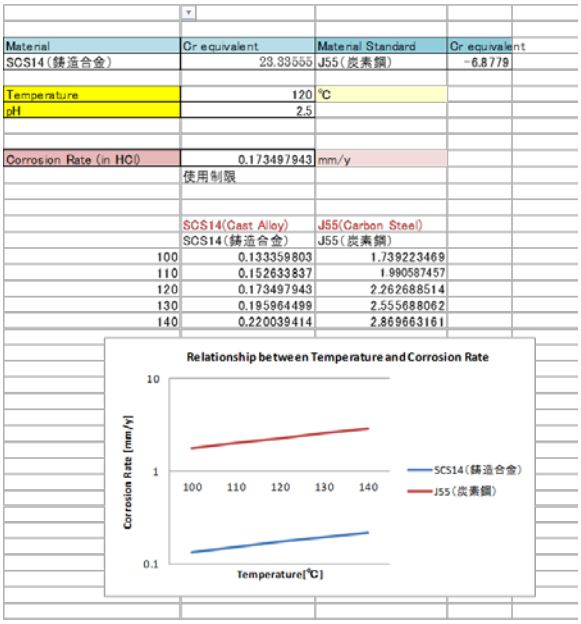

Figure 3: sample of the corrosion rate calculation system using Microsoft excel file

The corrosion rate is calculated in excel system, firstly select material and indicate Cr equivalent and secondly input the temperature and pH. And in this system, the estimated corrosion rate at from 100 to 140 degree C and compare the rate between selected material and carbon steel.

3. ON SITE CORROSION TEST AT KAKKONDA GEOTHERMAL FIELD

Corrosion and materials selection for casing, wellhead and downstream equipment has been identified as a major concern. Then, in this project, Quest Integrity NZL Ltd (Quest Integrity) assisted in the design and demonstration testing of a corrosion test loop at Kakkonda. Then, GERD constructed the test loop as shown in Figure 4. The loop system has three test point, the corrosometer was set at TEST1, the LPR probe was set at TEST2 and the several coupons were set at TEST3 in Figure 4.

This test loop system is connected the hot water line separated from the production well K6-5 at Kakkonda geothermal field. The geochemistry of fluid from this well as follows; pH is about 3.5, T-SiO_2 is 1,010mg/l, Na is 1,300mg/l, Cl is 2,330mg/l, Ca is 74mg/l, K is 232mg/l, SO_4 is 44mg/l and T-Fe is 25mg/l.

The temperature of test loop is controlled by the open ratio of valve at entrance of the test loop. The temperature is from 120 to 145 ºC.

The on-site test is carried out 6 times from 2 Nov. to 6 Nov. of 2015 and the detail of test condition as shown in Table 2.

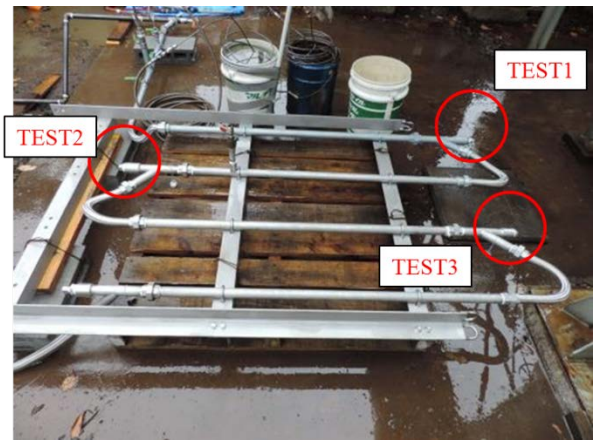

Figure 4: Corrosion test loop system at Kakkonda geothermal field

Table 2: The list of corrosion test at K6-5 at kakkonda geothermal field.

	Units	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
Date		3-Nov-15	3-Nov-15	3-Nov-15	4-Nov-15	5-Nov-15	6-Nov-15
Time Start		9:15 AM	12:10 PM	15:10 PM	9:20 AM	9:40 AM	11:07 AM
Time End		11:50 AM	2:50 PM	2015/11/4 8:30	2015/11/5 8:31	2015/11/6 9:05	13:07 PM
Duration	min	155	150	1038	1380	1410	120
Temperature	C	135	145	135	145	135	135
Pressure	MPa	0.22	0.32	0.22	0.32	0.22	0.22
Mass Flow	kg/h	0.5		0.5	0.5	0.5	0.5
Flow Velocity	m/sec	0.25		0.25	0.25	0.25	0.25
pH		about 3.6	3.6	3.6	3.6	3.6	3.6
Samples Exposed							
Test Point 1		CS Corrosometer	CS Corrosometer	CS Corrosometer	CS Corrosometer	CS Corrosometer	CS Corrosometer
Test Point 2		CS LPR	TN80S LPR	CS LPR	TN80Cr13 LPR	TN110CrSS LPR	CS LPR
Test Point 3		SS Dummy	SS Corrosometer	CS Dummy	Long Term	Long Term	CS Corrosometer

In this test, we try to measure the corrosion rate using the corroso-meter, LPR probe and cylinder coupon samples. And for cylinder coupon samples, we prepared four materials, K-55 (carbon steel), TN80SS (low alloy steel), TN80Cr13 and TN110Cr13S (stainless steel) and the several chemical composition of materials are shown in Table 3.

Table 3: The list of test material and chemical composition at K6-5 at Kakkonda geothermal field.

Material	C	Mn	Cr	Mo	Ni
K55	0.5	0.9	0	0	0
TN80SS	0.24	0.6	1	0.2	0
TN80SSCr13	0.2	0.5	13	0	0.2
TN110Cr13S	0.02	0.2	13	1	4.3

(wt%)

The size of cylinder coupon sample is about 30mm length with 8mm outer diameter and 5.2mm inner diameter and the set of nine samples and flow direction of hot fluid as shown in figure 5 in test loop system of Test 4 and Test 5.

After on-site test, we measured the weight change of the cylinder coupon samples and calculated average corrosion rate.

The list of samples and results are shown in Table 4. Firstly, we measured the weight difference by flow test. But several scales such as amorphous silica and metal minerals precipitated on samples, we remove the scale by washing using several acid and NaOH and we measured the weight after DHACP and calculate the corrosion thickness and corrosion rate for each test. And we estimate the average corrosion rate as follows; K-55 is 1.61 mm/year, TN80SS is 1.61 mm/year, TN80Cr13 is 0.17mm/year and TN110Cr13S is 0.03mm/year under 145 ºC and pH 3.6.

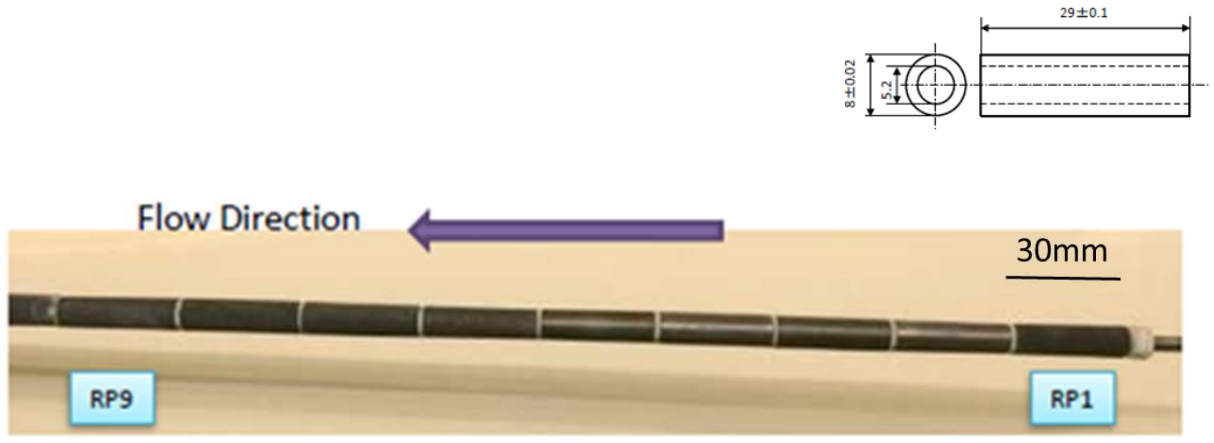

Figure 5: The size and shape of Cylinder coupon samples and flow direction of the corrosion test loop system.

Table 4: The list of corrosion rate of test materials at K6-5 at Kakkonda geothermal field.

Material	TEST-ID	Intial weight(g)	Exposuer time(hr)	Corrosion Thickness (mm)	C.R (mm/y)	C.R. Average (mm/y)
K-55	TEST-4RP1	6.4453	23.833	0.0038	1.4	1.61
	TEST-4RP9	6.4349	23.833	0.0033	1.2	
	TEST-5RP1	6.3351	23.417	0.0055	2.07	
	TEST-5RP9	6.4121	23.417	0.0047	1.76	
TN80SS	TEST-4RP8	6.4884	23.833	0.0039	1.45	1.61
	TEST-5RP8	6.3786	23.417	0.0047	1.76	
TN80Cr13	TEST-4RP4	6.3255	23.833	0.0004	0.15	0.17
	TEST-5RP4	6.2929	23.417	0.0005	0.18	
TN110Cr13SS	TEST-4RP3	6.2194	23.833	0.0001	0.03	0.03
	TEST-5RP3	6.2714	23.417	0.0001	0.04	

4. COMPARE THE CORROSION RATE BETWEEN ESTIMATION USING DATA BASE AND ON-SITE TEST

Using corrosion rate calculator of excel file shown in Figure 3, we estimated the corrosion rate of K-55 carbon steel, TN80SS, TN80Cr13 and TN110Cr13S under pH 3.6 at 135 and 145 ºC in Table 5. And in Table 5 show the average corrosion rate on-site test at Kakkanda geothermal field.

In the case of carbon steel K-55, the calculated corrosion rate is almost same as the average corrosion rate of on-site. And the TN80SS, the calculated corrosion rate is about half as the corrosion rate of on-site. On the other hand, TN80Cr13 and TN110Cr13S, the calculated corrosion rate is higher than the on-site corrosion rate.

Then, the equation of corrosion rate using Cr equivalent is useful for the estimation of the corrosion rate of carbon steel, K-55 in the case of one-day flow test at Kakkonda geothermal field. But in other materials, we have to check the relationship between estimation and on-site test, for example, by longer term test, in other filed or revise of Cr equivalent.

Table 5: The list of corrosion rate of test materials at K6-5 at Kakkonda geothermal field.

Material	135℃	145℃	On-site
K55	1.36	1.53	1.61
TN80SS	0.88	0.99	1.61
TN80SSCr13	0.32	0.36	0.17
TN110Cr13S	0.21	0.23	0.03

(mm/y)

5. SAMMARY

Several research about corrosion in the geothermal field was carried out by AIST-Tohoku from 1974 to 2002 and we have to review the activity. Especially, using pH, temperature and Cr equivalent material, the estimation of the corrosion rate was carried out. As the basis for this, the idea of Cr equivalent was introduced, and the ratio of the contribution to corrosion resistance of Cr and elements other than Cr was deduced from the experimental data.

And we compare the estimated corrosion rate using Cr equivalent with the on-site corrosion test at Kakkonda geothermal field at FY2015. The corrosion rate of carbon steel at Kakkonda is about 1.6mm/year at on-site examination and match to the result of calculation based on previous data-base.

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